

How Does Plant Population Density Affect the Yield, Quality, and Canopy of Native Bluestem (*Andropogon* spp.) Forage?

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ABSTRACT

The density at which a crop is grown is known to affect its growth and quality, but little is known about how plant density affects the growth of native perennial forage grasses. The objectives were to investigate the effects of plant population density on the forage yield, forage quality, and plant canopy structure of two native bluestem species. Big bluestem (*Andropogon gerardii* Vitman) and sand bluestem (*A. hallii* Hack.) were established at six plant densities (1.2, 1.8, 2.7, 3.6, 5.4, and 10.8 plants m⁻²) in a split plot experiment with whole plots in four randomized blocks. Plant density was the main plot and bluestem species was the split plot. Data were analyzed with a mixed model analysis of variance with blocks within year as random effects and year as a repeated measure. The optimum plant density for forage production was between 3.6 and 5.4 plants m⁻². However, the optimum for crude protein (CP) concentration occurred at 1.2 and 10.8 plants m⁻² and followed a quadratic response as plant density increased. The greatest leaf area index (LAI; leaf area per square meter) was at 10.8 plants m⁻². At 10.8 plants m⁻², the average yield loss from maximum was about 8.5% dry matter (DM). Also, the CP concentration was 8.5% greater for plants grown at 10.8 plants m⁻² than for those grown at 3.6 to 5.4 plants m⁻². A plant density of 10.8 plants m⁻² would produce high quality forage with only slight reductions in DM yield as compared with plants grown at 3.6 to 5.4 plants m⁻².

A GREAT DEAL is known about the effects of plant population density on the yield of horticultural and field crops (Boquet, 1990; Brown et al., 1970; Cuomo et al., 1998; Cusicanqui and Lauer, 1999; Lauer, 1995; Lege et al., 1993; Robinson and Nel, 1989; Wade and Douglas, 1990; Wade et al., 1988; Weerasinghe and Fordham, 1994; Widders and Price, 1989; Wilson and Dixon, 1988). However, plant density effects on native forage species is less well defined (Bolger and Meyer, 1983; Cooksley and Goward, 1988; Graybill et al., 1991; Jefferson and Kielly, 1998; Pinter et al., 1994; Sanderson and Reed, 2000; Springer et al., 2003). For field crops such as corn (*Zea mays* L.), sorghum (*Sorghum* spp.), and soybean [*Glycine max* (L.) Merr.], grain yield can be maximized by adjusting the seeding rates to match the moisture conditions of the environment, that is, densely populated stands utilize moisture and nutrients more quickly than sparsely populated stands (Jones and Johnson, 1991; Sanderson et al., 1996).

Plant morphology can affect plant density. Skalova and Krahulec (1992) found that tiller numbers of *Festuca*

rubra L. decreased as plant density increased. Similarly, Hiernaux et al. (1994) found that the main purpose of tillering was to compensate for low plant density that resulted from drought or intense grazing. Information on the effects of plant density on forage quality and feed value is limited to tropical forage corn or forage sorghums (Cuomo et al., 1998; Cusicanqui and Lauer, 1999; Pinter et al., 1994; Sanderson et al., 1996). These studies found little or no response of forage quality or feed value to plant population density. Understanding plant growth and development and forage quality of native warm-season grasses as they relate to the population density at which these grasses are grown will allow producers to improve the management and utilization of these forages. Our objectives were to investigate the effects of different plant population densities of two native bluestem (*Andropogon* spp.) species on forage yield, forage quality, and plant canopy structure.

MATERIALS AND METHODS

This study was conducted at the USDA-ARS, Southern Plains Range Research Station, Woodward, OK (36°25' N, 99°24' W, elevation 586 m) on an Eda loamy fine sand (mixed, thermic Lamellic Ustipsamment). In May 2000, two native bluestem species, big bluestem cv. Kaw and sand bluestem cv. Chet were transplanted at six plant population densities in a split plot experiment with whole plots in four randomized blocks. Plant density was the main plot and bluestem species was the split plot. Variable plot sizes were used to obtain the desired plant population densities. The treatments consisted of six population densities representing 1.2, 1.8, 2.7, 3.6, 5.4, and 10.8 plants m⁻². The actual plot dimensions, plant spacing within plot, number of plants per plot, harvested area, and number of plants harvested per plot are given in Table 1. During the establishment year, plots were maintained weed-free by hoeing, and dead plants were replaced to maintain the correct population densities. In subsequent years (2001–2003), plots were burned in March and atrazine [2-chloro-4-ethylamino-6-isopropylamino-s-triazine] was applied 7 to 14 d later for weed control at 1.68 kg a.i. ha⁻¹. Nitrogen was applied in the form of urea (46–0–0) at 70 kg N ha⁻¹ in April each year of the study.

Plant canopy height was measured before harvest each year by placing a meter stick near the center of each plot through the forage to the soil surface and reading the meter stick directly. Ten culms were randomly chosen from each plot and the number of leaves was counted for each culm and the leaf area for each culm was determined by passing its leaves through a LI-COR LI-3100C area meter (LI-COR Biosciences, Lincoln, NE). After forage harvest, the number of culms per plant was counted for five plants per plot. Culm density was calculated by multiplying the average number of culms per plant times the plant density per square meter. Leaf density was calculated

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Abbreviations: CP, crude protein; DM, dry matter; IVDMD, in vitro dry matter digestibility; LAI, leaf area index; LTA, long-term average.

Table 1. Actual plot dimensions, plant spacing within plot, number of plants per plot, harvested area, and number of plants harvested per plot for big bluestem and sand bluestem (*Andropogon* spp.) transplanted at six plant population densities.

Plant density plants m ⁻²	Plot dimensions		Plant spacing		Plants plot ⁻¹ no.	Harvested area m ⁻²	Plants harvested no.
	Width	Length	Row width	Within row			
			m				
1.2	2.74	3.66	0.91	0.91	12	3.33	4
1.8	2.74	3.66	0.91	0.61	18	3.33	6
2.7	3.04	3.66	0.61	0.61	30	4.46	12
3.6	2.74	3.66	0.91	0.30	36	3.33	12
5.4	3.04	3.35	0.61	0.30	55	4.09	22
10.8	2.74	3.35	0.30	0.30	99	4.09	44

by multiplying the average number of leaves per culm by the average number of culms per plant and the plant density per square meter. Leaf area index was calculated by multiplying the average leaf area per culm by the average number of culms per plant and the plant density per square meter.

Plots were harvested once each year in 2001 through 2003 to determine forage DM yield. The harvest dates were 25 July 2001, 17 July 2002, and 17 July 2003. The desired number of plants per plot (Table 1) was harvested by clipping a 1.2-m swath from the center of each plot. The distance harvested varied with plant population density. The harvested forage was weighed fresh and a 250- to 300-g subsample was collected for dry matter determination. Forage subsamples were oven-dried at 60°C until dry (approximately 72–96 h). The DM yield of each plot was calculated by multiplying the percentage DM of the oven-dried subsample by the harvested green weight of the plot and converted to megagrams per hectare. Crude protein was determined using the Micro-Kjeldahl procedure (AOAC, 1997) and in vitro dry matter digestibility (IVDMD) was determined using the procedures of Tilley and Terry (1963) as modified by White et al. (1981).

Data for forage DM yield, CP concentration, IVDMD, canopy height, culm density, leaf density, and LAI were analyzed as a mixed model analysis of variance with blocks within year as random effects and year as a repeated measure (Littell et al., 1996; SAS Institute, Inc., 1999). Fixed effects were species and plant density and species × plant density interaction. The variable plant density was also partitioned into linear and quadratic effects using orthogonal polynomials (SAS Institute, Inc., 1999).

RESULTS

The April through July rainfall was 86 mm above the long-term average (LTA) in 2001, 14 mm below the LTA in 2002, and 118 mm below the LTA in 2003 (Table 2).

Averaged across years 2001 through 2003, the cumulative rainfall for April through July was 18 mm above the LTA. The average high and low temperatures were near the LTA during April through July 2001 to 2003 (Table 2).

Plant population density and species affected the forage DM yield of native bluestems ($P < 0.01$). As the plant density increased the DM yield responded somewhat quadratically (quadratic effects, $P < 0.01$; Fig. 1) and no interaction occurred between species and plant density ($P = 0.69$). Forage DM yield peaked between 3.6 and 5.4 plants m⁻² and stayed relatively constant through 10.8 plants m⁻². The DM yield of Chet sand bluestem exceeded that of Kaw big bluestem by an average of 4.0 Mg ha⁻¹; ranging from 2.6 Mg ha⁻¹ at 1.2 plants m⁻² to 4.8 Mg ha⁻¹ at 10.8 plants m⁻². The large standard error around each mean is due to the differences between the two species.

Plant density did not effect the CP concentration of bluestem forage ($P = 0.15$); however, there was a quadratic response for plant density (quadratic effect, $P < 0.01$; Fig. 2), and there was an effect due to species ($P < 0.01$), but no interaction was found between plant density and species ($P = 0.21$). The average CP concentration of Chet sand bluestem was 56 ± 2 g kg⁻¹ compared with 65 ± 2 g kg⁻¹ for Kaw big bluestem. Similarly, the large standard error around each mean is due to the differences between the two species.

Plant density did not affect IVDMD ($P = 0.60$), but species differed in IVDMD concentrations ($P < 0.01$). The IVDMD for Chet sand bluestem averaged 511 ± 16 g kg⁻¹ compared with 566 ± 16 g kg⁻¹ for Kaw big bluestem. The species × plant density interaction for

Table 2. Precipitation and temperatures received on the experiment in 2001 through 2003.

	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Precipitation, mm												
Long-term average	13	25	46	53	102	81	66	74	58	48	36	20
2001 total	47	57	55	31	212	120	25	37	128	0	4	1
2002 total	2	0	2	86	45	82	75	57	48	234	5	24
2003 total	2	10	47	35	37	111	1	93	75	10	16	17
Temperature high, °C												
Long-term average	9	12	17	23	27	32	35	34	29	24	16	10
2001 average	8	9	14	24	26	32	37	35	28	23	18	12
2002 average	11	12	16	23	26	32	33	34	30	21	16	9
2003 average	10	8	17	23	26	28	36	35	26	23	14	12
Temperature low, °C												
Long-term average	-6	-3	2	7	13	18	21	19	15	8	1	-4
2001 average	-3	-3	2	10	13	18	24	21	14	8	6	-2
2002 average	-3	-3	-2	9	12	19	21	20	16	8	2	-2
2003 average	-4	-4	2	8	12	17	22	21	13	9	3	-2

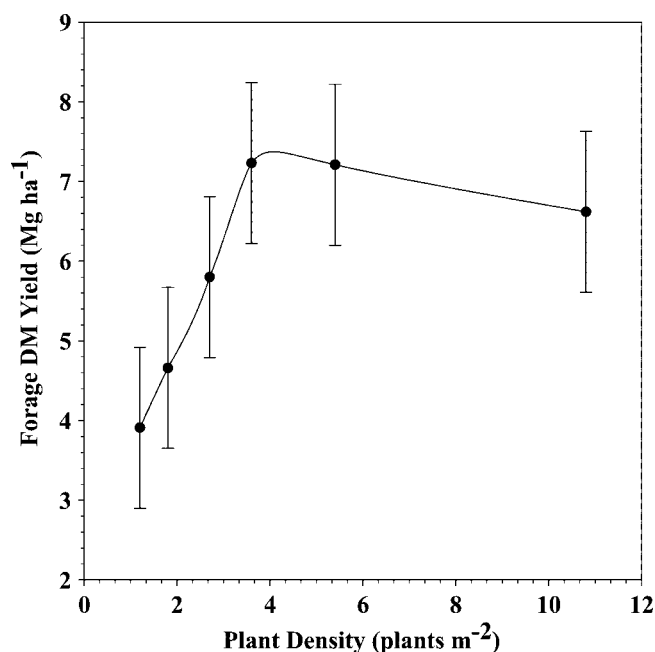


Fig. 1. Average forage dry matter (DM) yield of *Andropogon* spp. grown at six plant densities. A line was added to the plot to aid in data interpretation. Each data point is the mean \pm SE of 24 experimental units averaged across years and species.

IVDMD was not significant ($P = 0.73$), and linear and quadratic effects were lacking ($P > 0.45$).

Plant canopy height at harvest was not affected by plant density ($P = 0.17$); however, as plant density increased the canopy height decreased linearly (linear effect, $P < 0.02$; Fig. 3). Canopy height was affected by species ($P < 0.01$), but there was no interaction between plant density and species ($P = 0.16$). The canopy height

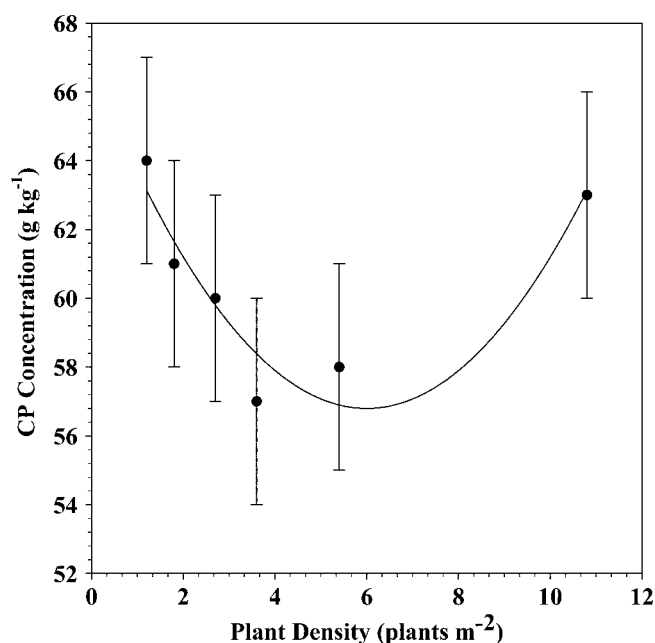


Fig. 2. Average crude protein (CP) concentration of *Andropogon* spp. grown at six plant densities. A line was added to the plot to aid in data interpretation. Each data point is the mean \pm SE of 24 experimental units averaged across years and species.

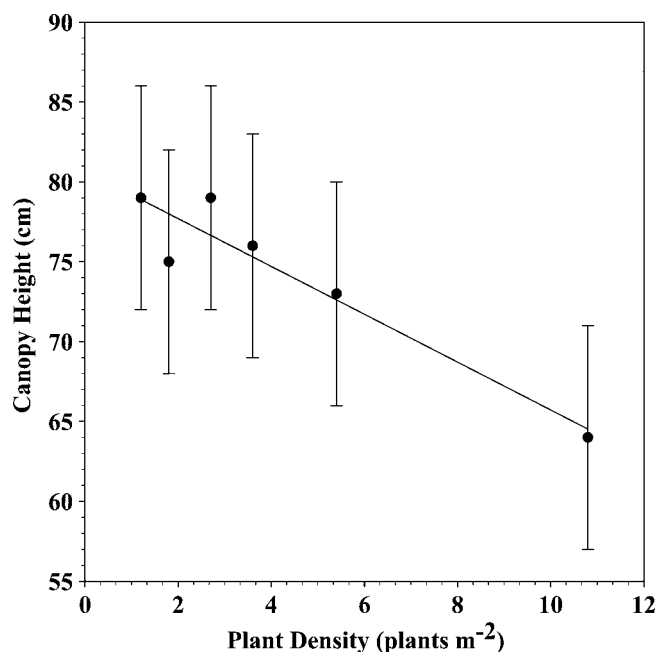


Fig. 3. Average plant canopy height of *Andropogon* spp. grown at six plant densities. A line was added to plot to aid in data interpretation. Each data point is the mean \pm SE of 24 experimental units averaged across years and species.

of Kaw big bluestem averaged 57 ± 6 cm compared with 91 ± 6 cm for Chet sand bluestem. The large standard error around each mean is due to the differences between the two species.

The culm density was affected only by plant density ($P < 0.01$). As the plant density increased the culm density increased linearly (linear effect, $P < 0.01$; Fig. 4). The culm density ranged from 131 ± 77 culms for 1.2 plant m^{-2} to 578 ± 77 culms for 10.8 plant m^{-2} . The

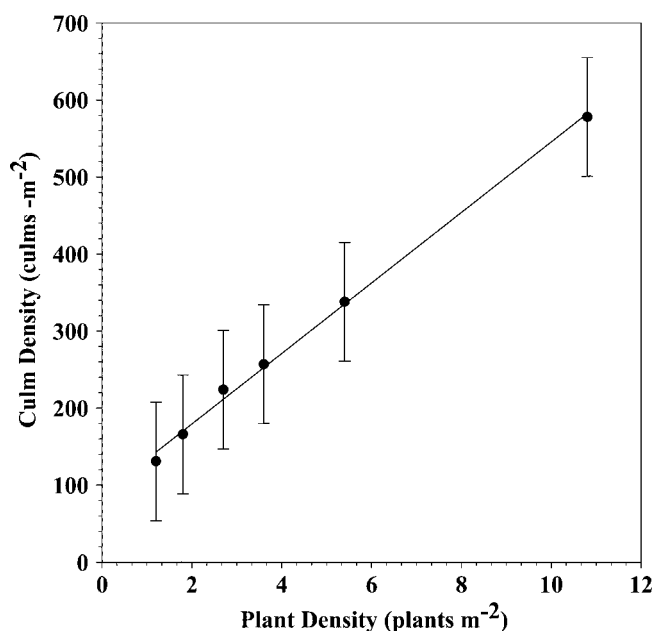


Fig. 4. Average culm density of big bluestem and sand bluestem plants grown at six plant densities. A line was added to plot to aid in data interpretation. Each data point is the mean \pm SE of 24 experimental units averaged across years and species.

large standard error around each mean is due to the differences between the two species.

There was a plant density \times species interaction for leaf density ($P < 0.08$). With increasing plant density, the leaf density for each species increased linearly (linear effect, $P < 0.01$; Fig. 5). Chet sand bluestem had a significantly greater leaf density at 10.8 plants m^{-2} and had a greater rate of increase as compared with Kaw big bluestem.

Leaf area index was affected by a plant density \times species interaction ($P < 0.09$; Fig. 6). As plant density increased the LAI for each species increased curvilinearly (linear and quadratic effects, $P < 0.01$). The average LAI for Kaw big bluestem was 16 ± 3.5 compared with 19 ± 3.5 for Chet sand bluestem. Similar to leaf density, the LAI of Chet sand bluestem was significantly greater at the 10.8 plants m^{-2} density.

DISCUSSION

The forage DM yield of big bluestem and sand bluestem peaked between 3.6 and 5.4 plants m^{-2} . In comparison, the DM yield of irrigated eastern gamagrass [*Tripsacum dactyloides* (L.) L.] peaked at 4.8 plants m^{-2} (Springer et al., 2003) and falls within the range found for these two species, but was lower than the 10.0 plants m^{-2} reported for forage corn (Cusicanqui and Lauer, 1999) and the 22.2 plants m^{-2} reported for irrigated forage sorghum (Sanderson et al., 1996).

The similarity of optimum plant densities for big and sand bluestem was surprising, given their differences in growth habit and forage production. Big bluestem has a bunch-type habit in the Southern Plains and tends to grow on heavier, clay soils. Sand bluestem, on

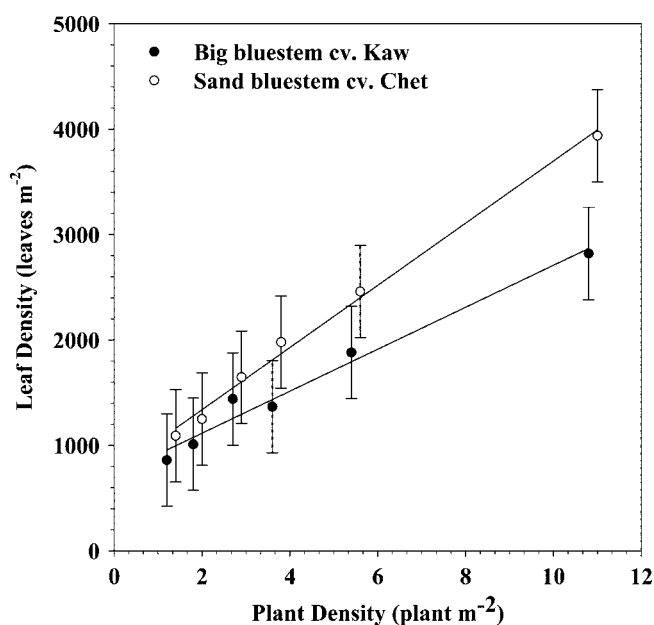


Fig. 5. Average leaf density of big bluestem and sand bluestem grown at six plant densities. Data points were slightly offset to eliminate hidden information and lines were added to plot to aid in data interpretation. Each data point is the mean \pm SE of 12 experimental units averaged across years.

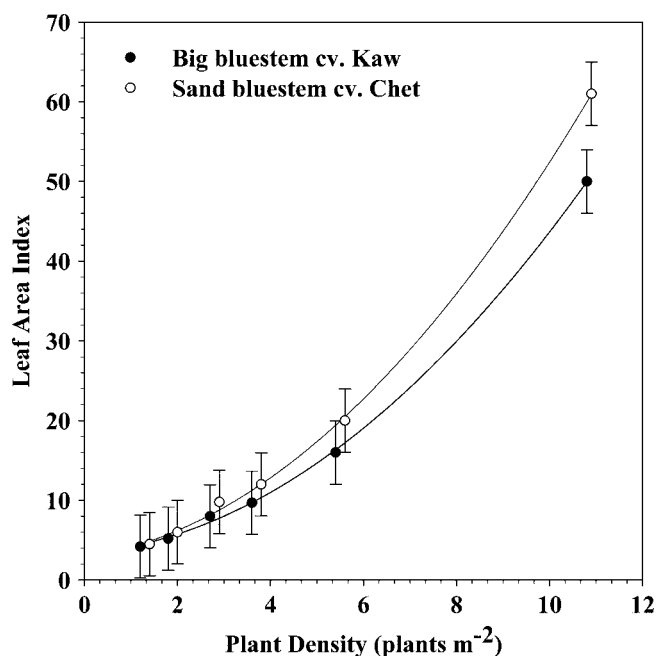


Fig. 6. Average leaf area index of big bluestem and sand bluestem grown at six plant densities. Data points were slightly offset to eliminate hidden information and lines were added to plot to aid in data interpretation. Each data point is the mean \pm SE of 12 experimental units averaged across years.

the other hand, has a sod-forming habit and tends to grow on lighter, sandier soils. Sand bluestem produced more above-ground biomass than big bluestem on sandy soils in the Southern Plains (Springer, unpublished data, 2005).

The CP concentration responded quadratically as plant density increased. This is contrary to reports by Cusicanqui and Lauer (1999) and Widdicombe and Thelen (2002) with forage corn. They found negative linear responses for CP concentration as plant density increased. The quadratic response is likely due to two simultaneous events. The first is a dilution effect of the N content as the DM yield increases to its maximum and the second is due to leaf/stem ratio. Leaf density increased as plant density increased. Furthermore, canopy height decreased as plant density increased, indicating less stem and a higher leaf/stem ratio. It is well known that leaf blades have higher CP concentrations compared with the leaf sheaths or internode stems (Kalmbacher, 1983).

Leaf/stem ratio may partially explain the difference in IVDMD for big bluestem and sand bluestem. Sand bluestem was 60% taller than big bluestem at harvest. Sand bluestem, however, had only 30% greater leaf area per square meter than big bluestem. Thus, big bluestem has a higher leaf/stem ratio as compared with sand bluestem. The other factors that influence nutritive value of forages, that is, temperature, water deficits, solar radiation, and nutrient availability, were the same for all plant densities, which may explain the lack of differences among plant densities.

The linear decline in canopy height is indicative of density-related stress among plants of the same species, in that plants compensate their growth on the basis of

their population density (Harper, 1977, p. 152). Plants at higher densities will generally be shorter and have less biomass compared with plants at lower densities. One would expect to find an increase in culm density as plant density increased. In this experiment, as the plant density increased by 1 plant m^{-2} , culm density increased 46 culms m^{-2} , but culms per plant decreased by five. Hiernaux et al. (1994) reported the main purpose of tillering by annual grasses in the Sahel was to compensate for low plant density. This also seems to be the case for *Andropogon* species. Plants at low densities are not limited by resources necessary for growth to the same extent as plants at higher densities. The growth of plants at high densities will eventually come to an equilibrium when a growth factor becomes limiting.

There was no difference in leaf density for big and sand bluestem at low plant densities, but differences occurred at high plant densities. Given the fact that the culm density was not different for the two species, the differences seen between the two species for number of leaves per square meter was due to the number of leaves per culm. Sand bluestem had 0.7 more leaves per culm than did big bluestem at 1.2 plant m^{-2} . Sand bluestem had 1.4 more leaves per culm than did big bluestem at 10.8 plants m^{-2} . This difference in the number of leaves per culm accounts for the species \times density interaction found for this variable.

The effects of plant density on LAI followed much the same pattern as leaf density. Leaf area increased as plant density increased, but at low plant densities there was not any difference between big bluestem and sand bluestem. Only at 10.8 plants m^{-2} was there a significant difference between big bluestem and sand bluestem. Retta et al. (2000) reported a positive linear relationship between leaf mass and leaf area for several native grasses including big bluestem. Thus, in our experiment, more leaf area would translate into more leaf mass.

CONCLUSIONS

On the basis of DM forage yield, the optimum plant population density ranged between 3.6 and 5.4 plants m^{-2} . This, however, may not be the optimum if other parameters are considered. A plant density of 10.8 plants m^{-2} would yield more leaf mass on the basis of the LAI. Forage CP concentration was lowest for plants growing at 3.6 to 5.4 plant m^{-2} , but was highest for plants growing at either the 1.2 or 10.8 plants m^{-2} . The forage yield loss of growing plants at 10.8 plants m^{-2} versus that of 3.6 to 5.4 plants m^{-2} ranged from about 6% for sand bluestem to about 20% for big bluestem. Conversely, there was about an 8.5% increase in CP concentration for plants grown at 10.8 plants m^{-2} . Thus, for optimum forage value and highest forage quality a plant density of 10.8 plants m^{-2} (a plant spaced every 900 cm^2) would be best.

REFERENCES

Association of Official Analytical Chemists. 1997. Official methods of analysis of AOAC International. 16th ed. Method 976.06H. AOAC, Gaithersburg, MD.

- Bolger, T.P., and D.W. Meyer. 1983. p. 37–41. Influence of plant density on alfalfa yield and quality. Proc. Am. Forage Grassland Council, Eau Claire, WI. 22–26 Jan. 1983. AFGC, Georgetown, TX.
- Boquet, D.J. 1990. Plant population density and row spacing effects on soybean at post-optimal planting dates. Agron. J. 82:59–64.
- Brown, R.H., E.R. Beatty, W.J. Ethredge, and D.D. Hayes. 1970. Influence of row width and plant population on yield of two varieties of corn. Agron. J. 62:767–770.
- Cooksley, D.G., and E.A. Goward. 1988. Effect of plant density and spatial arrangement on the yield of *Leucaena leucocephala* cv. Peru in subcoastal southeastern Queensland. Aust. J. Exp. Agric. 28:577–585.
- Cuomo, G.J., D.D. Redfearn, and D.C. Blouin. 1998. Plant density effects on tropical corn forage mass, morphology, and nutritive value. Agron. J. 90:93–96.
- Cusicanqui, J.A., and J.G. Lauer. 1999. Plant density and hybrid influence on corn forage yield and quality. Agron. J. 91:911–915.
- Graybill, J.S., W.J. Cox, and D.J. Otis. 1991. Yield and quality of forage maize as influenced by hybrid, planting date, and plant density. Agron. J. 83:559–564.
- Harper, J.L. 1977. Population biology of plants. Academic Press, New York.
- Hiernaux, P., P.N. De Leeuw, and L. Diarra. 1994. Modeling tillering of annual grasses as a function of plant density: Application to Sahelian rangelands productivity and dynamics. Agric. Syst. 46: 121–139.
- Jefferson, P.G., and G.A. Kielly. 1998. Reevaluation of row spacing/plant density of seeded pasture grasses for the semiarid prairie. Can. J. Plant Sci. 78:257–264.
- Jones, O.R., and G.L. Johnson. 1991. Row width and plant density effects on Texas High Plains sorghum. J. Prod. Agric. 4:613–621.
- Kalmbacher, R.S. 1983. Distribution of dry matter and chemical constituents in plant parts of four Florida native grasses. J. Range Manage. 36:298–301.
- Lauer, J.G. 1995. Plant density and nitrogen rate effects on sugar beet yield and quality early in harvest. Agron. J. 87:586–591.
- Lege, K.E., C.W. Smith, and J.T. Cothren. 1993. Planting date and planting density effects on condensed tannin concentration of cotton. Crop Sci. 33:320–324.
- Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS System for mixed models. SAS Institute Inc., Cary, NC. 633 pp.
- Pinter, L., Z. Alföldi, Z. Burucs, and E. Paldi. 1994. Feed value of forage maize hybrids varying in tolerance to plant density. Agron. J. 86:799–804.
- Retta, A., D.V. Armbrust, L.J. Hagen, and E.L. Skidmore. 2000. Leaf and stem area relationships to masses and their height distributions in native grasses. Agron. J. 92:225–230.
- Robinson, J.C., and D.J. Nel. 1989. Plant density studies with banana (cv. Williams) in a subtropical climate. II. Components of yield and seasonal distribution of yield. J. Hort. Sci. 64:211–222.
- Sanderson, M.A., R.M. Jones, and R.C. Read. 1996. Management of forage sorghum: Nitrogen, plant density and irrigation effects on yield and quality. Texas J. Agric. Resources 9:61–78.
- Sanderson, M.A., and R.L. Reed. 2000. Switchgrass growth and development: Water, nitrogen, and plant density effects. J. Range Manage. 53:221–227.
- SAS Institute, Inc. 1999. SAS/STAT user's guide, Version 8, Cary, NC.
- Skalova, H., and F. Krahulec. 1992. The response of three *Festuca rubra* clones to changes in light quality and plant density. Funct. Ecol. 6:282–290.
- Springer, T.L., C.L. Dewald, P.L. Sims, and R.L. Gillen. 2003. How does plant population density affect the forage yield of eastern gamagrass? Crop Sci. 43:2206–2211.
- Tilley, J.M.A., and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18:104–111.
- Wade, L.J., and A.C.L. Douglas. 1990. Effect of plant density on grain yield and yield stability of sorghum hybrids differing in maturity. Aust. J. Exp. Agric. 30:257–264.
- Wade, L.J., C.P. Norris, and P.A. Walsh. 1988. Effects of suboptimal plant density and non-uniformity in plant spacing on grain yield of rain grown sunflower. Aust. J. Exp. Agric. 28:617–622.
- Weerasinghe, S.S., and R. Fordham. 1994. The effects of plant density

- on onions established from multiseeded transplants. *Acta Hort.* 371:97–104.
- Widders, I.E., and H.C. Price. 1989. Effects of plant density on growth and biomass partitioning in pickling cucumbers. *J. Am. Soc. Hortic. Sci.* 114:751–755.
- Widdicombe, W.D., and K.D. Thelen. 2002. Row width and plant density effects on corn forage hybrids. *Agron. J.* 94:326–330.
- Wilson, F., and G.R. Dixon. 1988. Strawberry growth and yield related to plant density using matted row husbandry. *J. Hortic. Sci.* 63:221–227.
- White, L.M., G.P. Hartman, and J.W. Bergman. 1981. In vitro digestibility, crude protein, and phosphorus content of straw of winter wheat, spring wheat, barley, and oat cultivars in eastern Montana. *Agron. J.* 73:117–121.